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(54) **LOCALIZED ENERGY DISSIPATION
STRUCTURES FOR VEHICLES**

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B60Y 2306/01 (2013.01)

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(56) **References Cited**

U.S. PATENT DOCUMENTS

4,911,495	A	3/1990	Haga et al.
5,464,266	A	11/1995	Guertler
5,542,738	A	8/1996	Walker et al.
5,573,298	A	11/1996	Walker et al.
5,765,906	A	6/1998	Iwatsuki et al.
5,822,927	A	10/1998	Hellenkamp et al.
6,283,539	B1 *	9/2001	Enning et al. 296/203.03
6,325,451	B1	12/2001	Sikorski
6,357,822	B1	3/2002	Panoz et al.
6,546,693	B2 *	4/2003	Wycech 52/790.1

(Continued)

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FOREIGN PATENT DOCUMENTS

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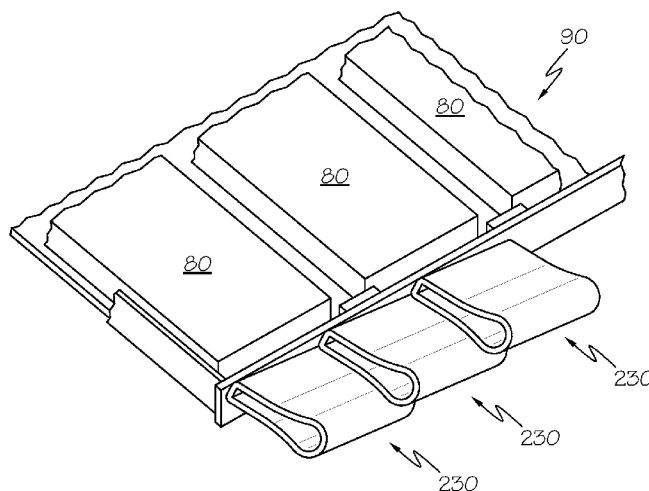
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B60K 1/04 (2006.01)
B62D 21/15 (2006.01)

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CPC **B62D 25/025** (2013.01); **B60K 1/04**

(57) **ABSTRACT**

An impact protection structure for a vehicle impacting a blunt-object barrier includes a support structure of the vehicle, an energy absorbing rail coupled to the support structure, and a localized energy dissipation structure. The energy absorbing rail extends an energy absorbing rail length and includes a plurality of lumens. The localized energy dissipation structure extends a localized energy dissipation structure length less than the energy absorbing rail length.

13 Claims, 15 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

6,834,912 B2 * 12/2004 Cardimen et al. 296/204
 6,890,021 B2 * 5/2005 Bock et al. 296/187.02
 6,951,366 B2 * 10/2005 Tomita 296/187.08
 7,147,272 B2 * 12/2006 Odaka et al. 296/187.12
 7,407,219 B2 8/2008 Glasgow et al.
 7,537,273 B2 5/2009 Lassl et al.

7,617,916 B2 11/2009 Heatherington et al.
 7,695,056 B2 4/2010 Hanson, Jr. et al.
 7,874,600 B2 1/2011 Hashimura
 7,992,920 B2 8/2011 Deng et al.
 8,066,322 B2 * 11/2011 Mori 296/187.03
 8,366,185 B2 * 2/2013 Herntier 296/209
 8,608,232 B2 * 12/2013 Engertsberger et al. . 296/187.12
 2011/0169302 A1 7/2011 Deng et al.
 2014/0028053 A1 * 1/2014 Hihara 296/187.12

* cited by examiner

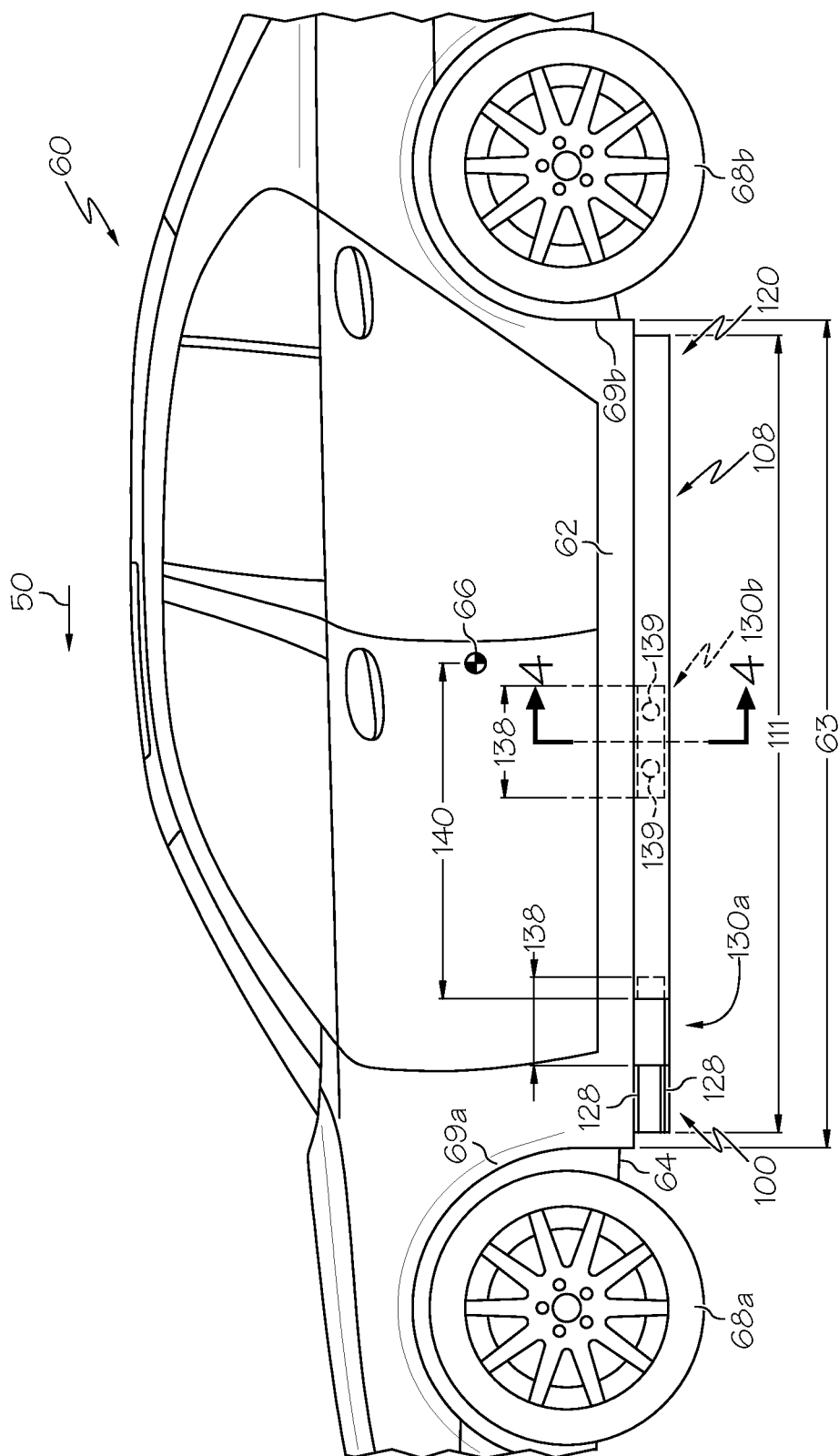


FIG. 1

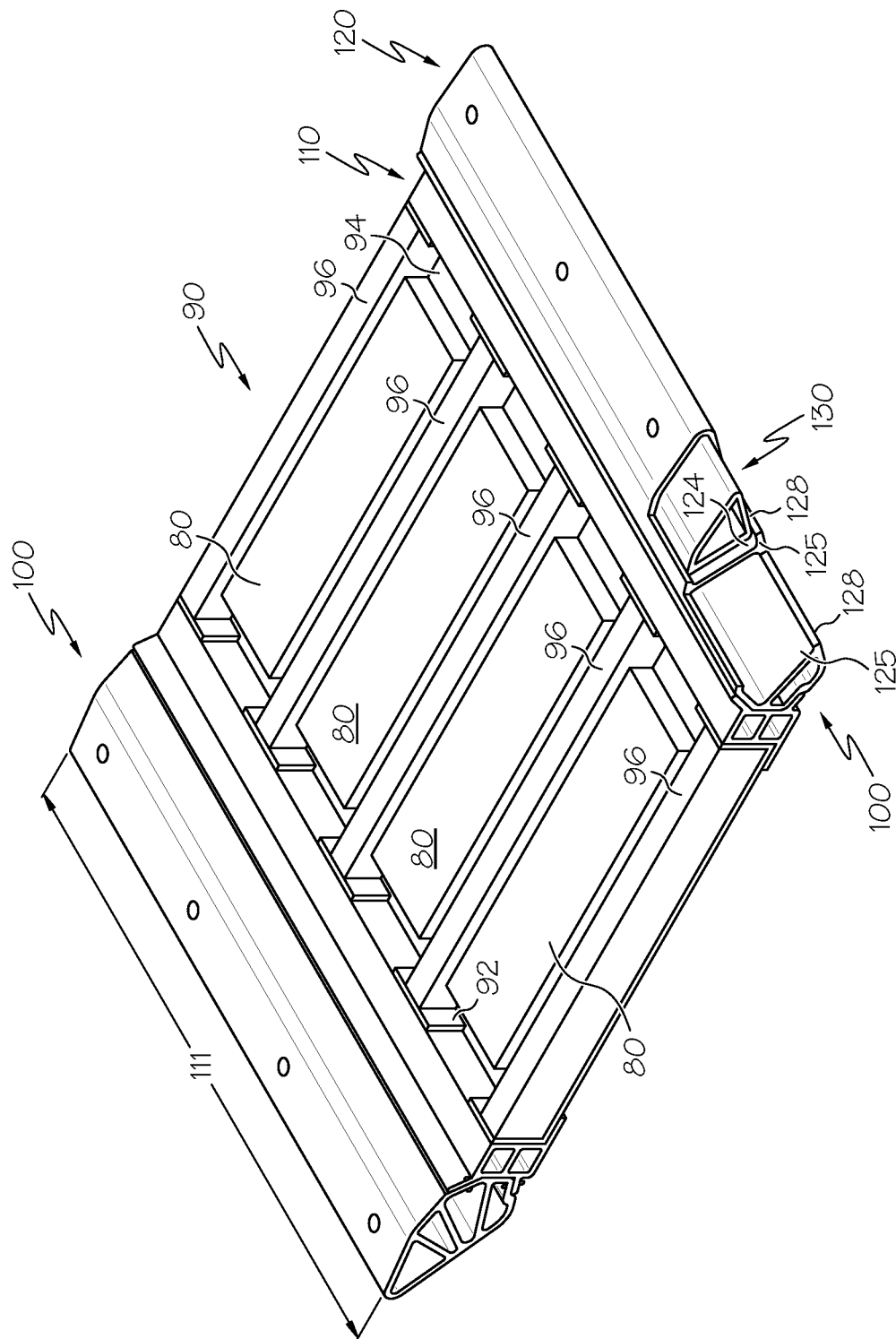
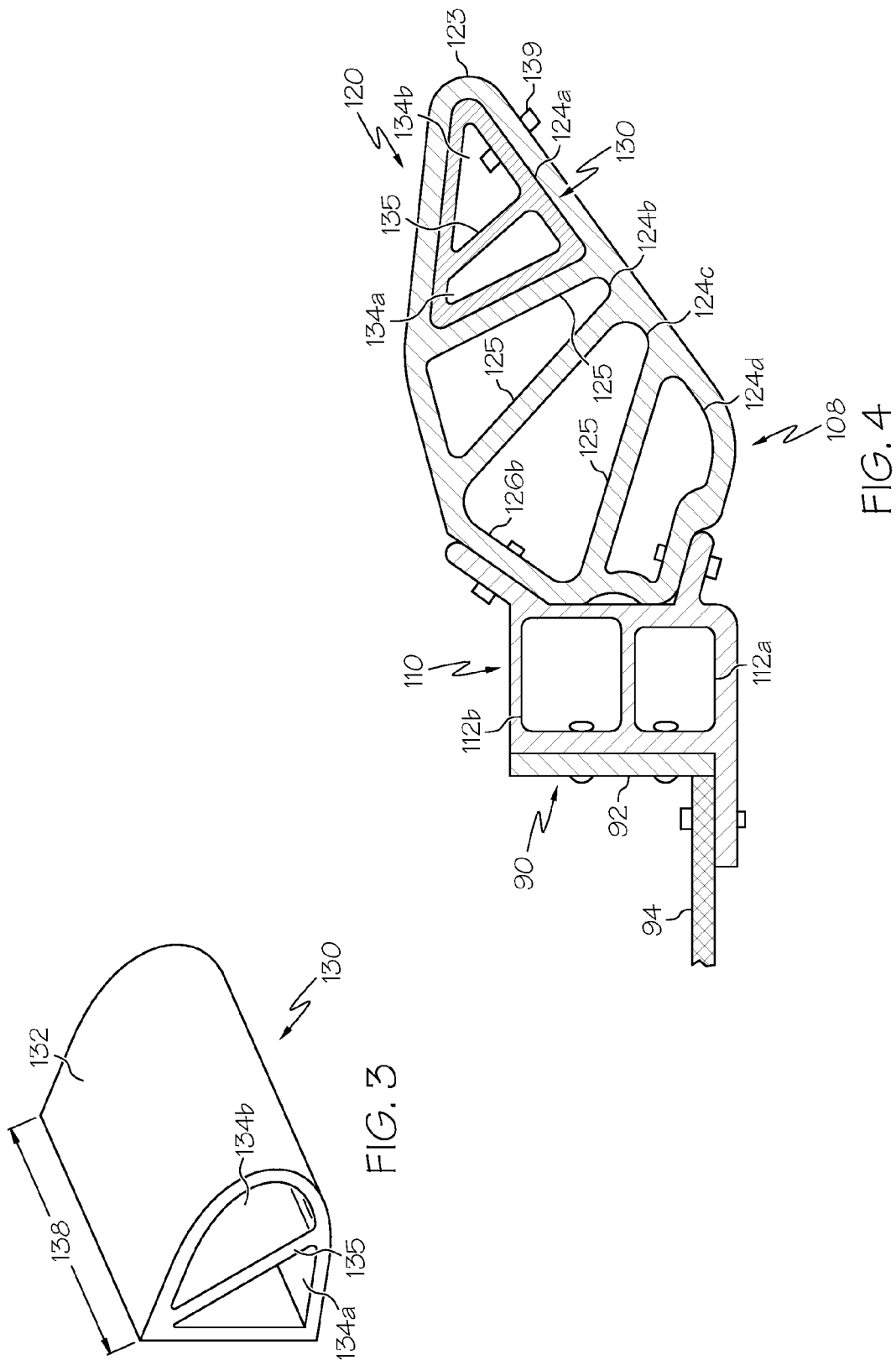


FIG. 2



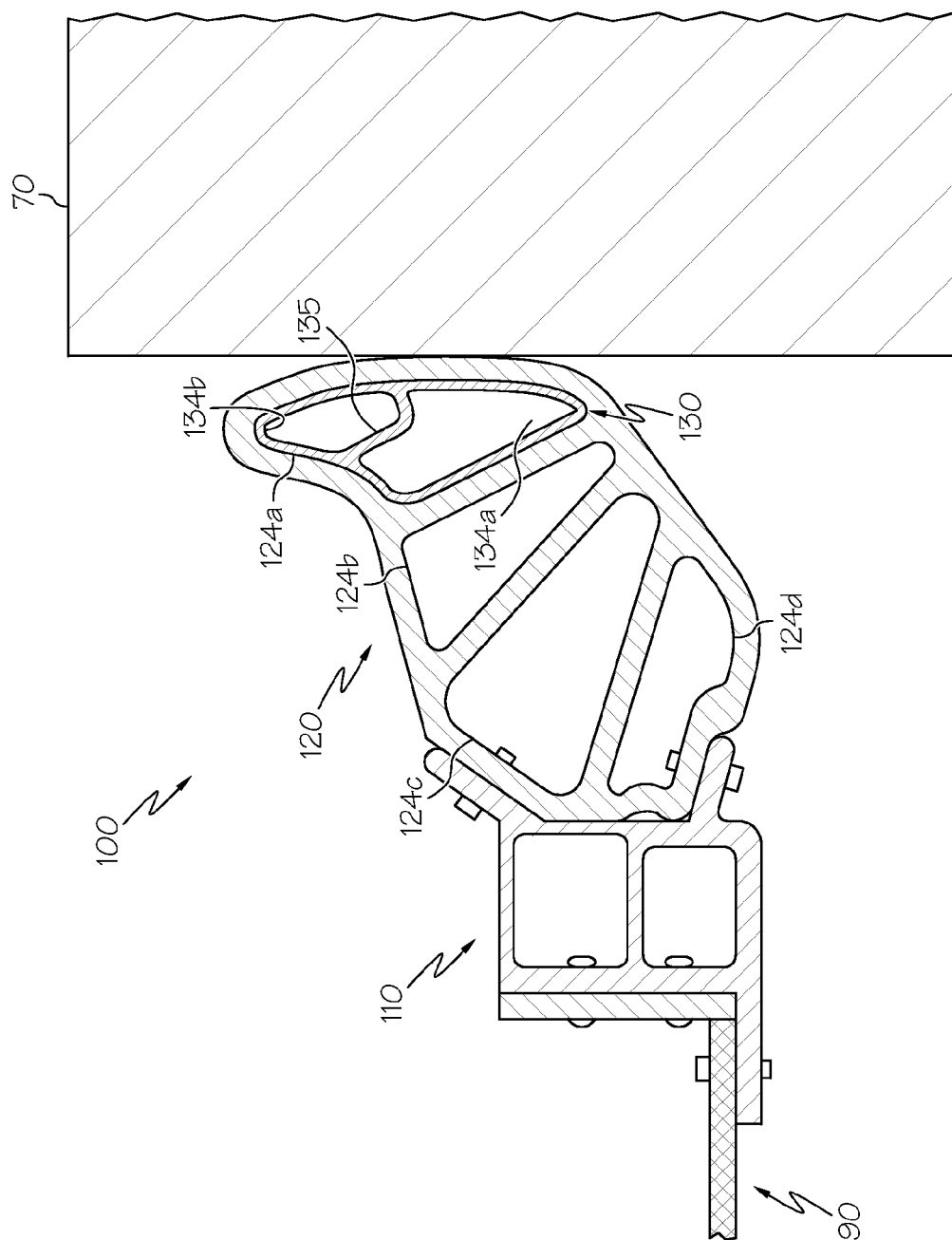


FIG. 5

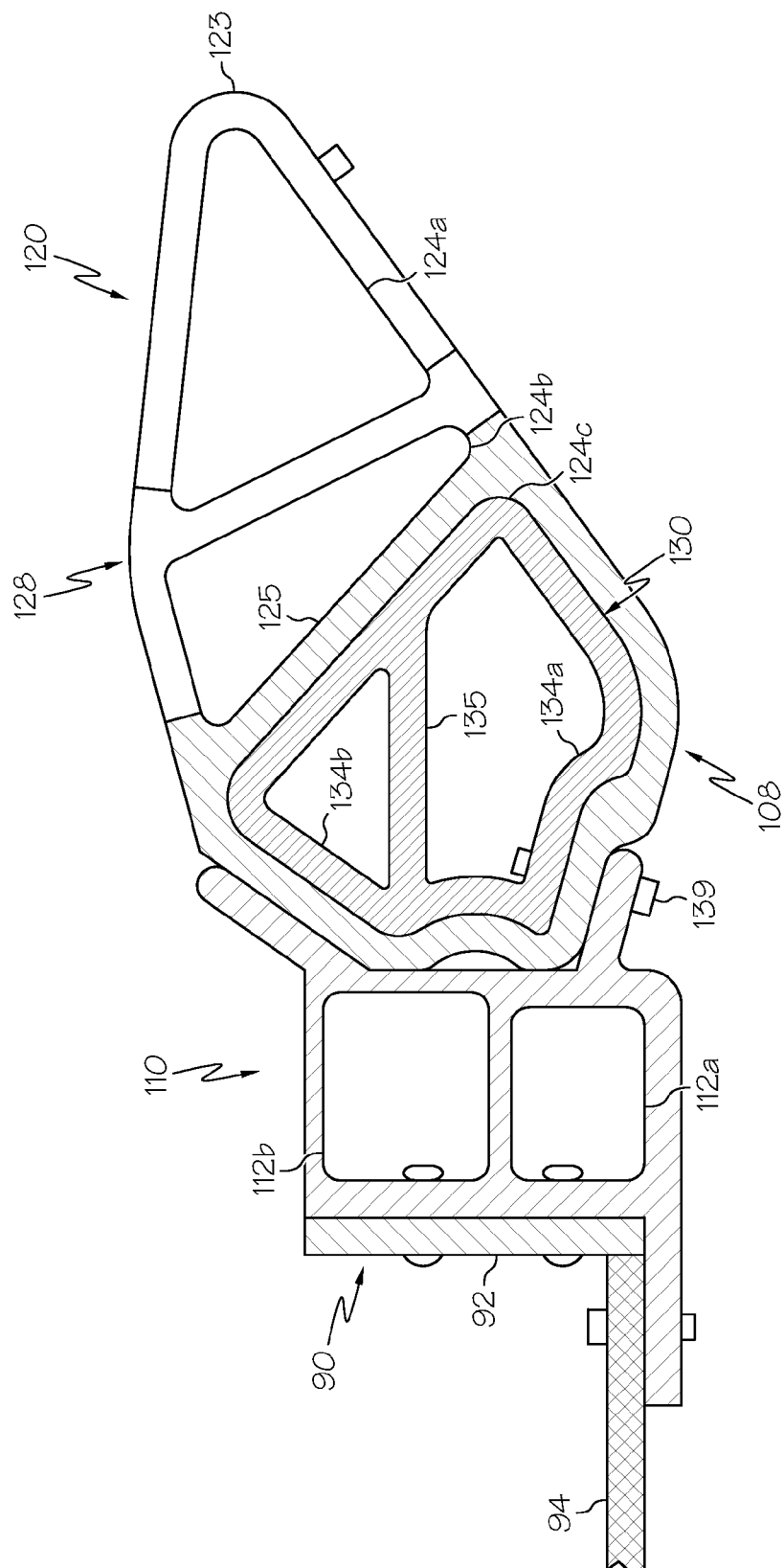


FIG. 6

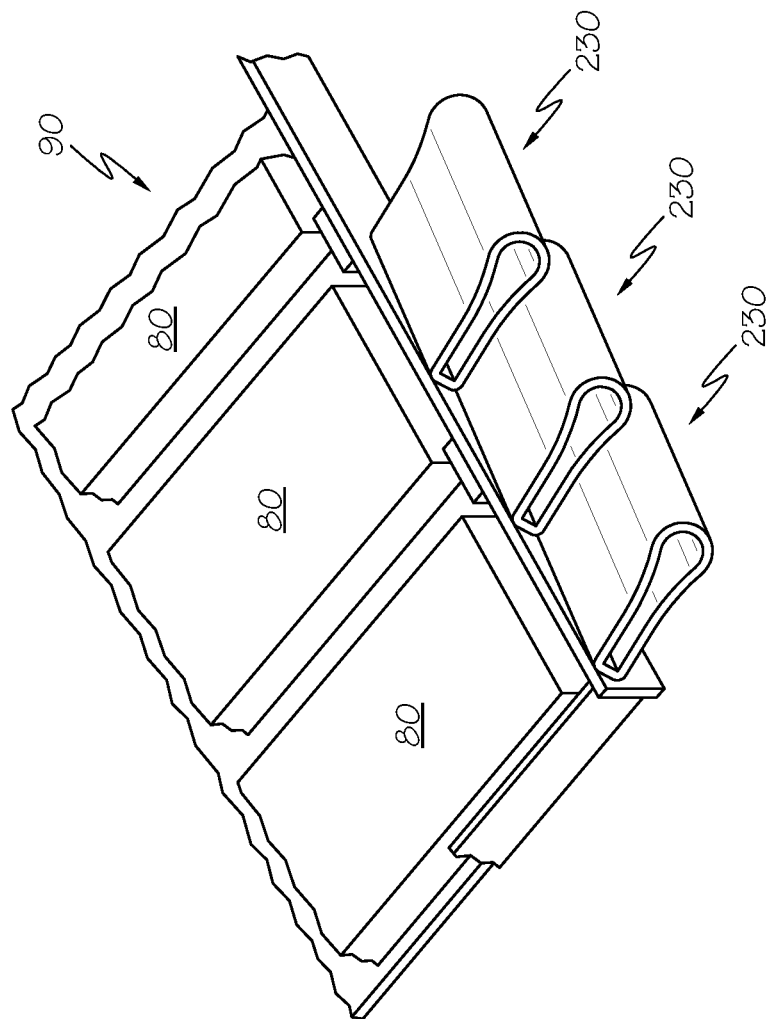


FIG. 7

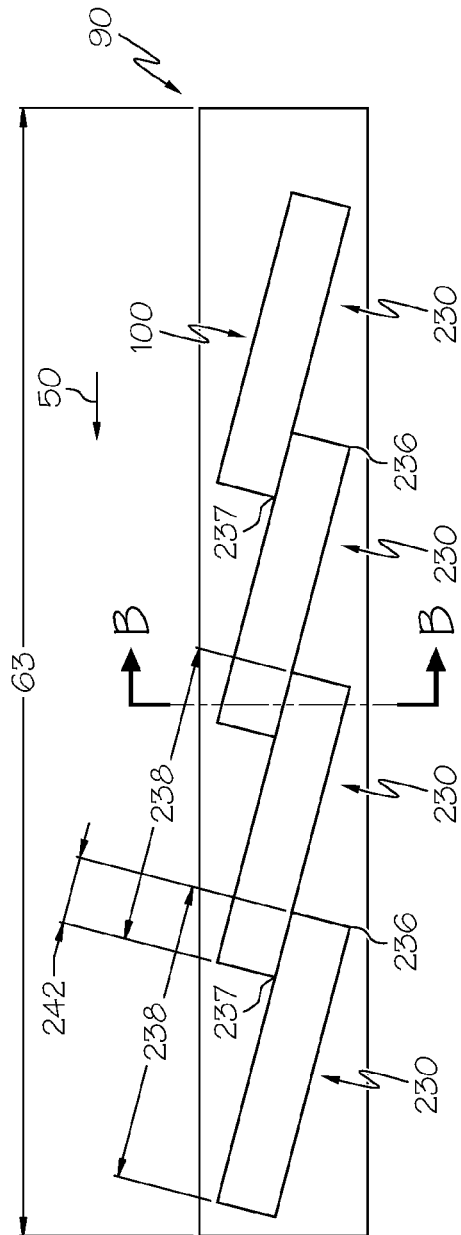


FIG. 8

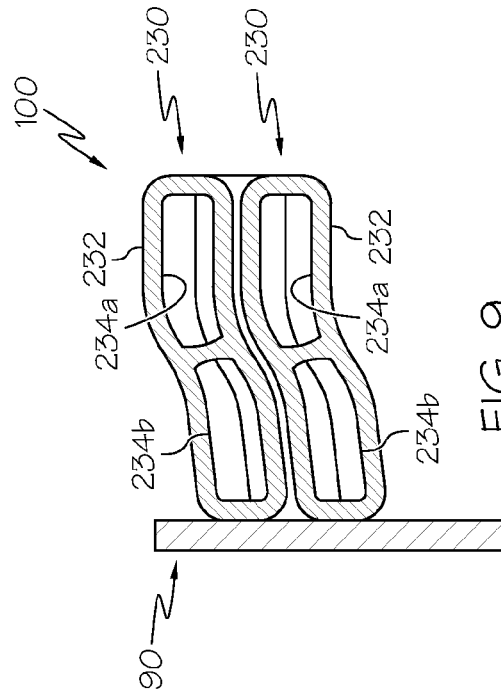


FIG. 9

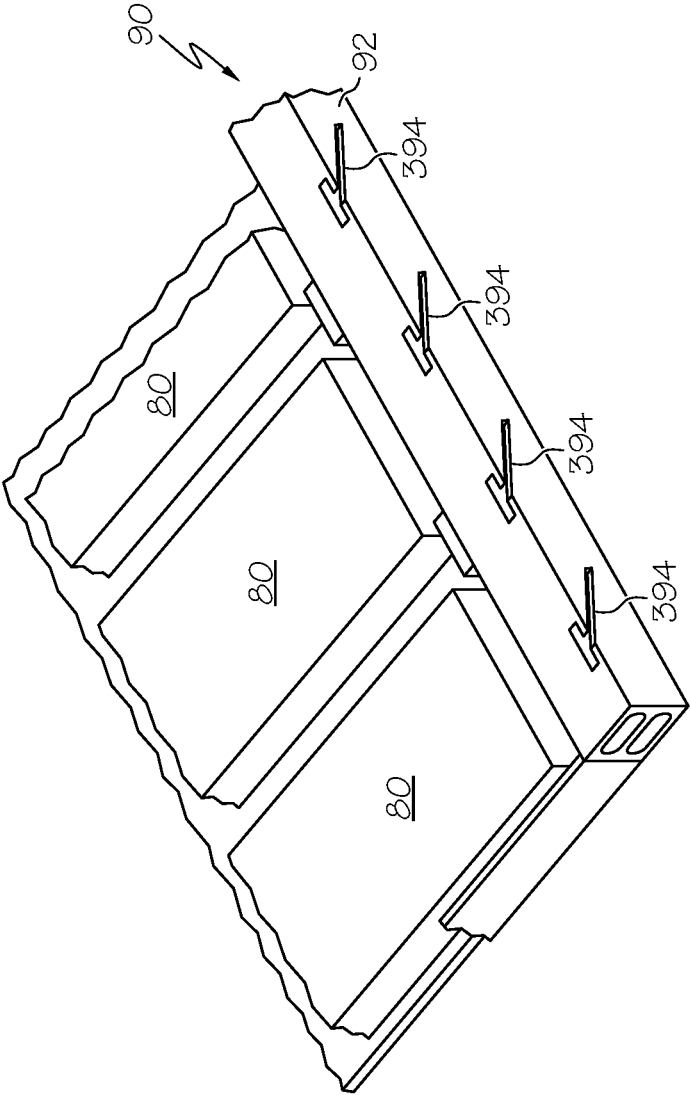


FIG. 10

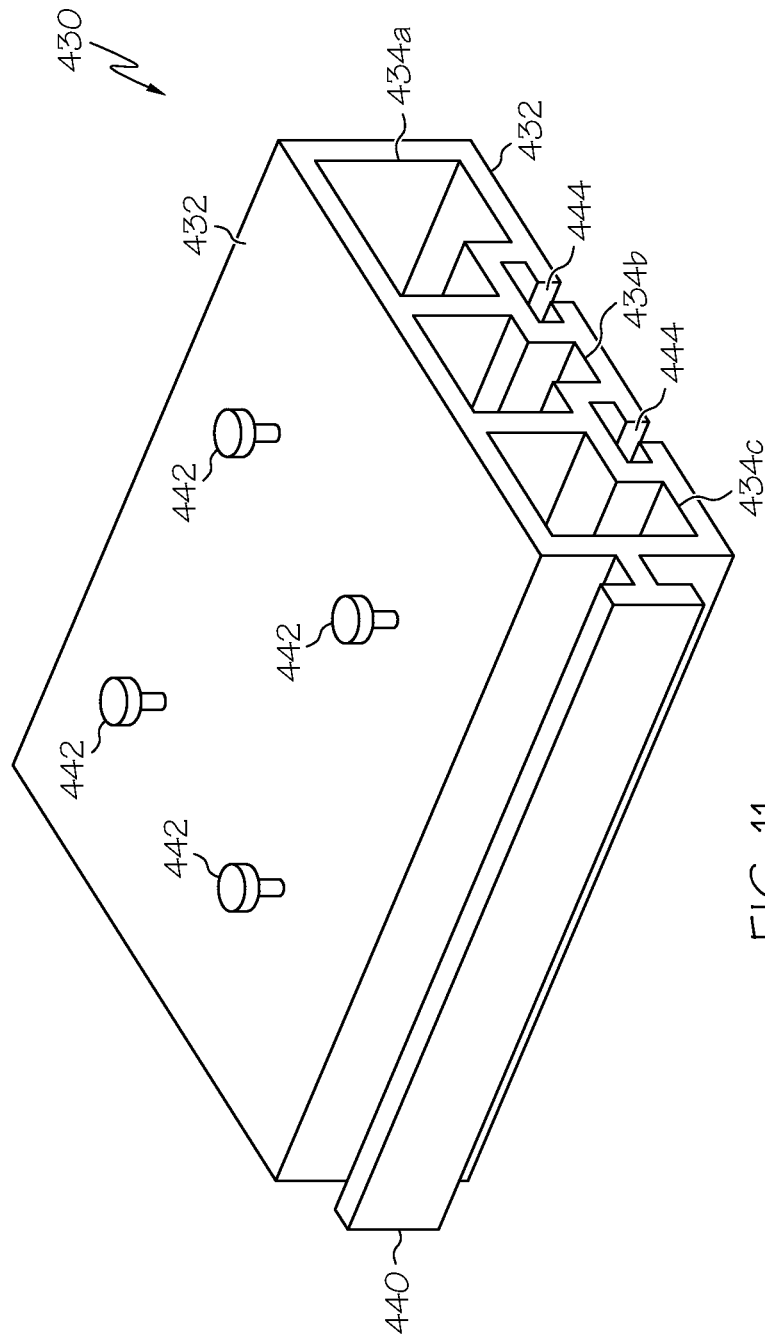


FIG. 11

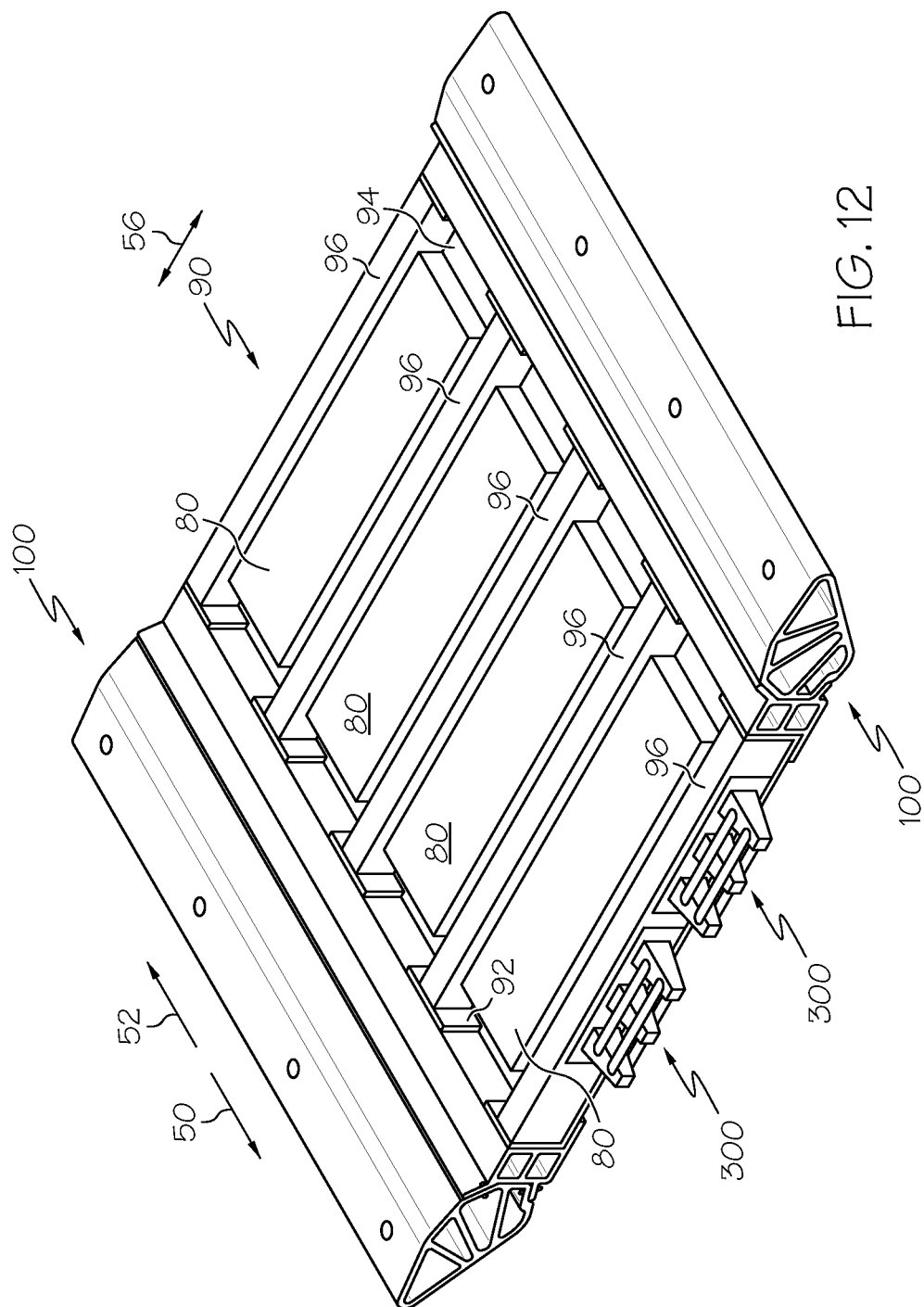
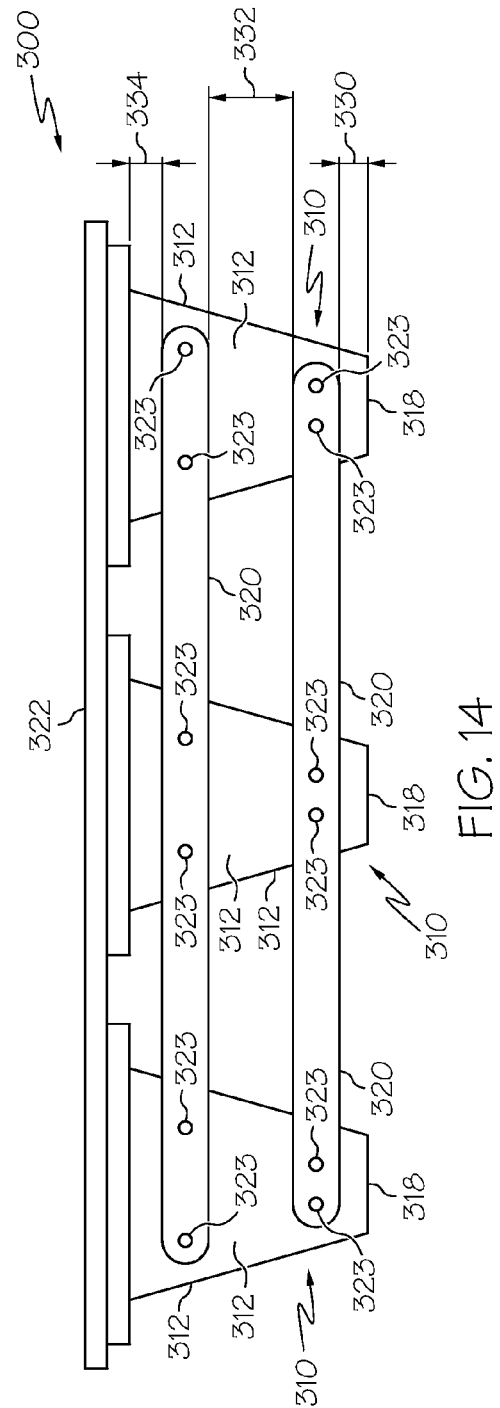
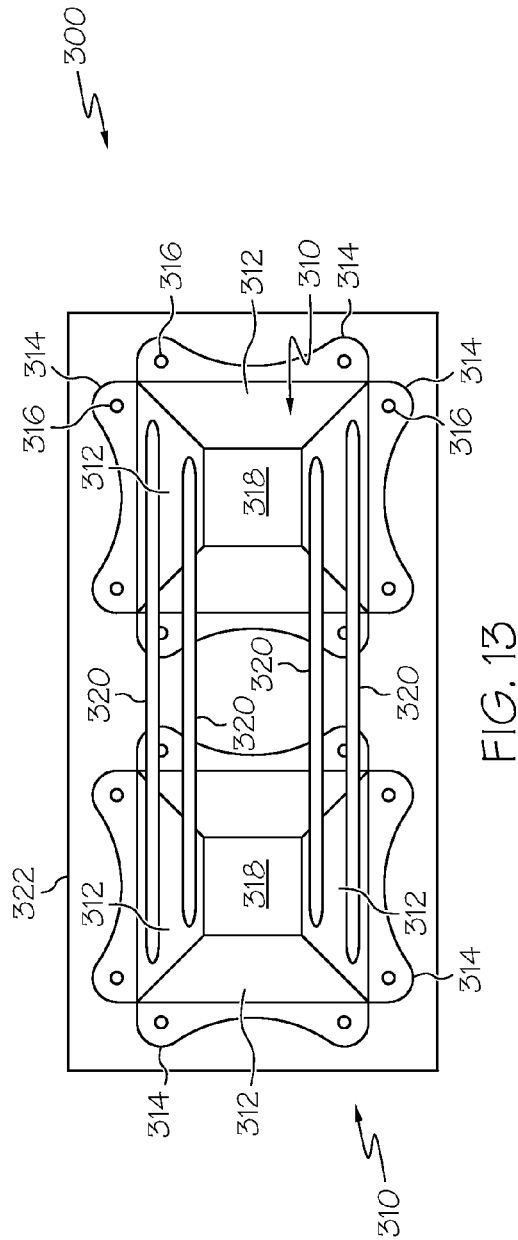


FIG. 12



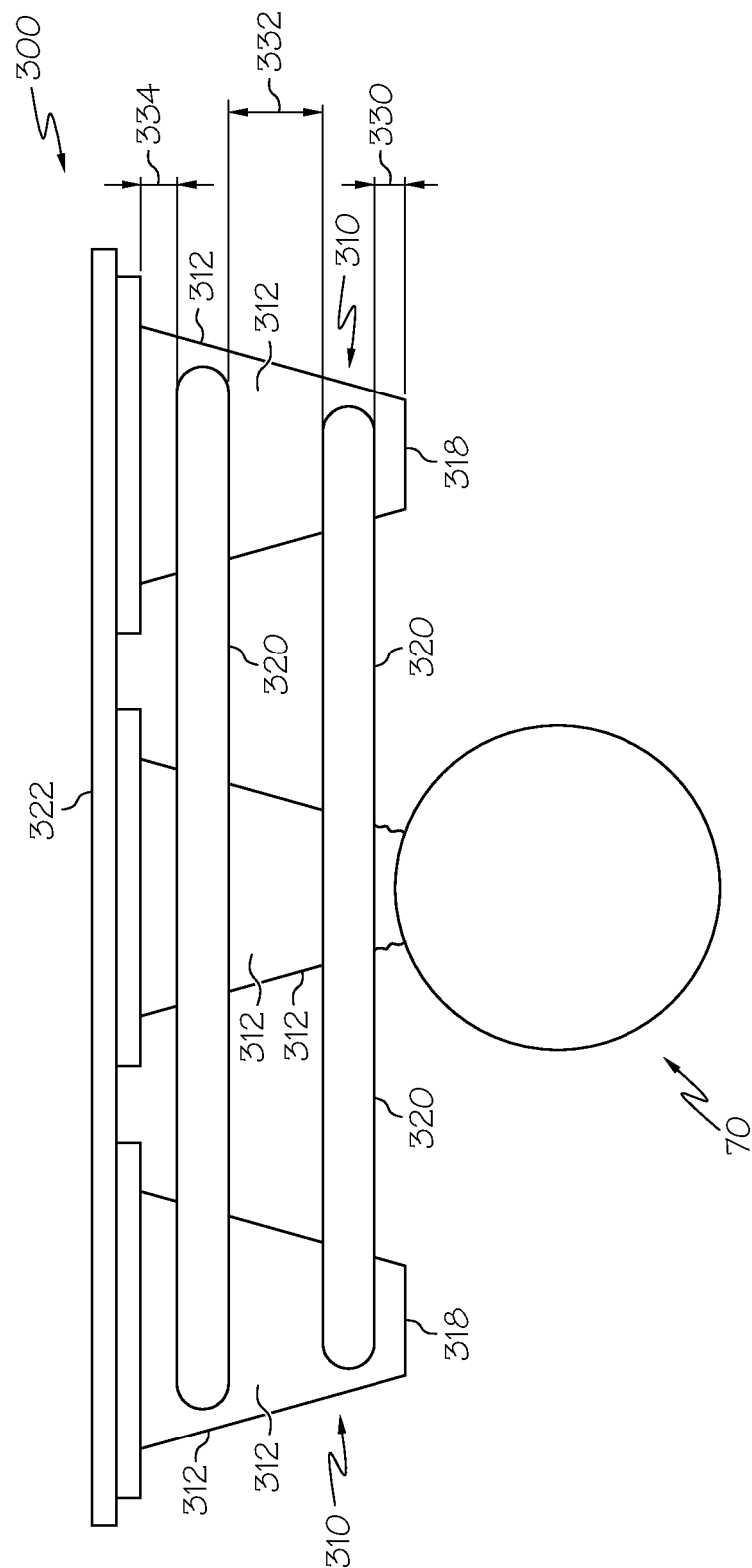


FIG. 15

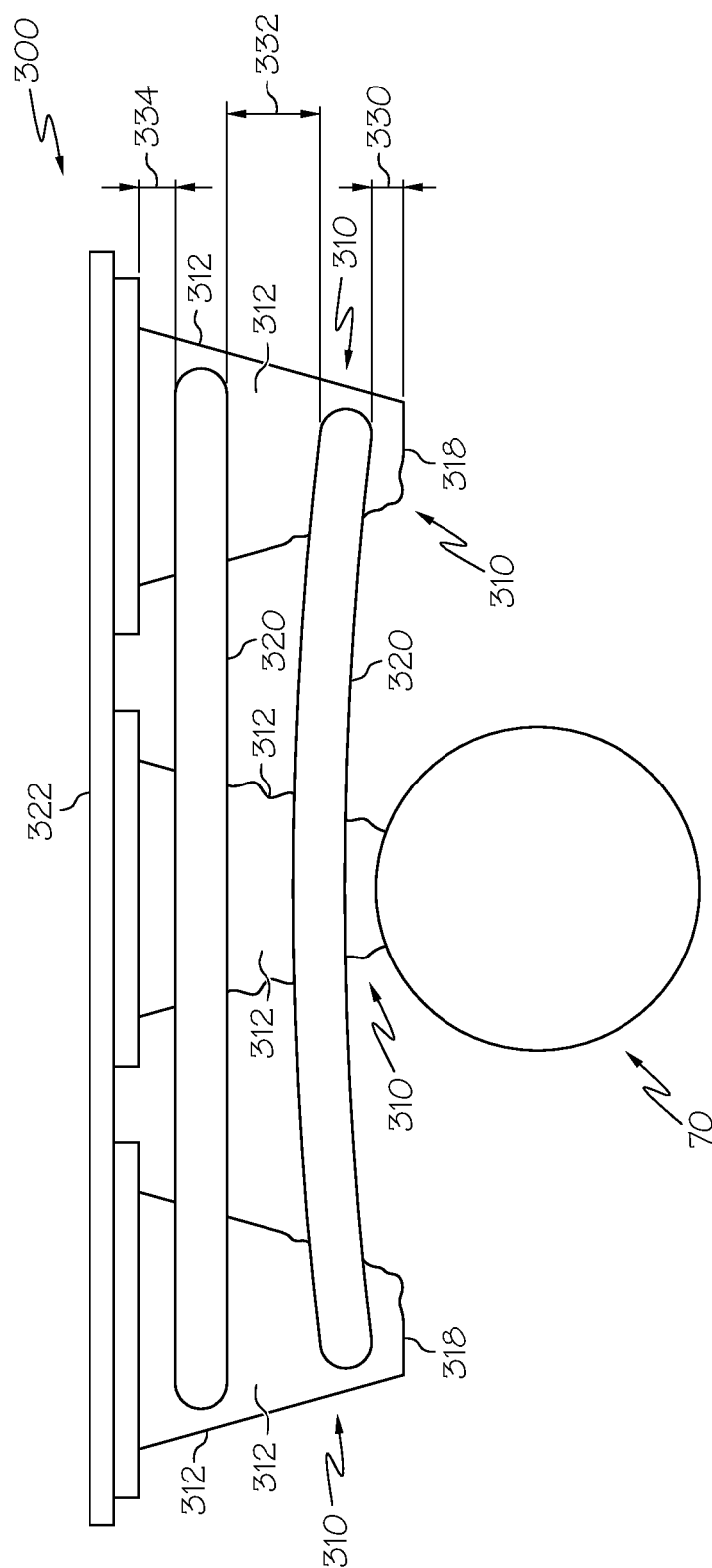
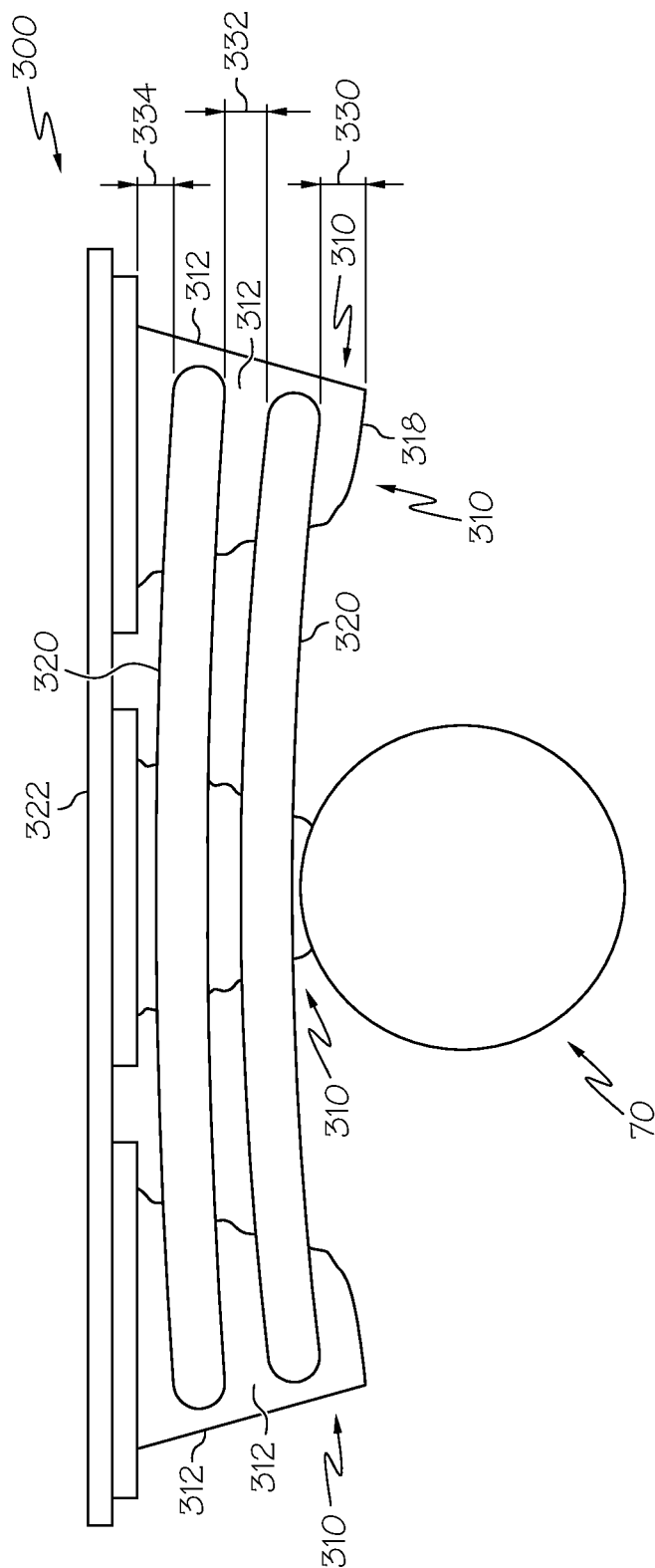


FIG. 16



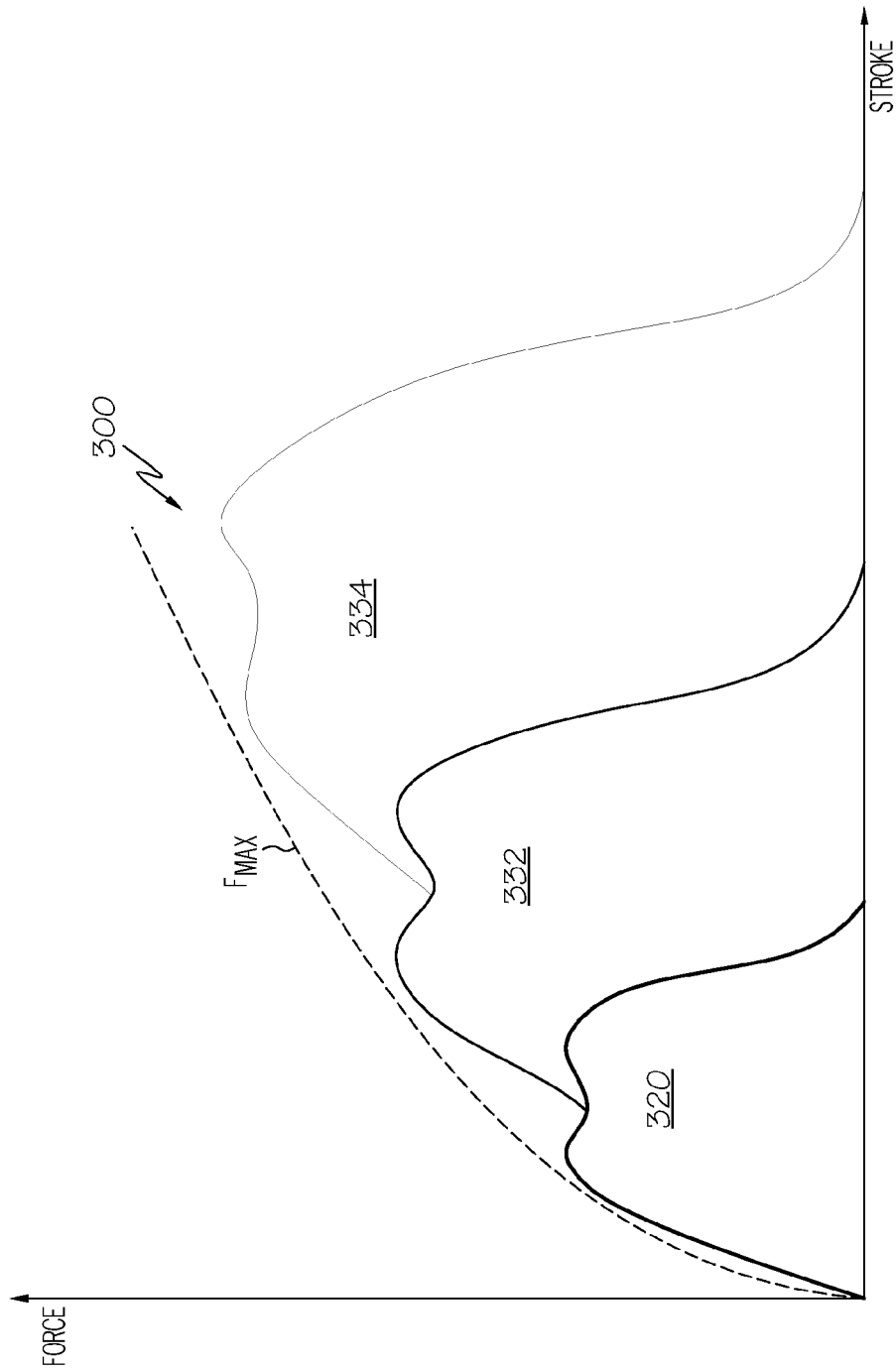


FIG. 18

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LOCALIZED ENERGY DISSIPATION STRUCTURES FOR VEHICLES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 13/446,810, titled "Localized Energy Dissipation Structures for Vehicles," filed on Apr. 13, 2012, the entire disclosure of which is hereby incorporated by reference.

TECHNICAL FIELD

The present specification generally relates to localized energy dissipation structures for vehicles and, more specifically, to localized energy dissipation structures for vehicles that dissipate energy associated with an impact with a blunt-object barrier at discrete locations along a portion of the vehicle.

BACKGROUND

Passenger vehicles must be capable of withstanding the high forces experienced during collisions. In the United States, vehicles must comply with the Federal Motor Vehicle Safety Standards (FMVSS) and Insurance Institute for Highway Safety protocols, which describe, among other specifications, crashworthiness and vehicle integrity standards.

In addition to the standards applicable to conventional, gasoline or diesel-fueled vehicles, in electric and hybrid-electric vehicles, it is important to protect the integrity of the battery packs that are used to power the vehicle. The energy that is required to be dissipated by an impact protection structure may vary depending on the location and the orientation of the impact protection structure. Accordingly, a need exists for localized energy dissipation structures for vehicles and vehicles incorporating the same.

SUMMARY

In one embodiment, an impact protection structure for a vehicle impacting a blunt-object barrier includes a support structure of the vehicle, an energy absorbing rail coupled to the support structure, and a localized energy dissipation structure. The energy absorbing rail extends an energy absorbing rail length and includes a plurality of lumens. The localized energy dissipation structure extends a localized energy dissipation structure length less than the energy absorbing rail length.

In another embodiment, an impact protection structure for a vehicle includes a side sill of the vehicle extending a side sill distance between a front wheel well and a rear wheel well, and a plurality of localized energy dissipation structures coupled to the side sill, the localized energy dissipation structures each having a localized energy dissipation structure length less than the side sill distance.

In yet another embodiment, an impact protection structure for a vehicle includes a support structure for the vehicle, a mounting bracket coupled to the support structure, and a plurality of elongated frustums coupled to the mounting bracket. Each of the elongated frustums includes a plurality of lateral faces extending from the mounting bracket to a distal contact face, where the lateral face at the lowest vertical position is angled upwards in a direction from the mounting bracket to the distal contact face. When the elongated frustum is subject to an impact load, the elongated frustum deforms to absorb energy from the impact load.

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These and additional features provided by the embodiments described herein will be more fully understood in view of the following detailed description, in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments set forth in the drawings are illustrative and exemplary in nature and not intended to limit the subject matter defined by the claims. The following detailed description of the illustrative embodiments can be understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

FIG. 1 schematically depicts a partial side view of a vehicle having an impact protection structure positioned along the side of the vehicle according to one or more embodiments shown or described herein;

FIG. 2 schematically depicts a perspective view of a support structure and impact protection structures for a vehicle according to one or more embodiments shown or described herein;

FIG. 3 schematically depicts a perspective view of a localized energy dissipation structure for an impact protection structure according to one or more embodiments shown or described herein;

FIG. 4 schematically depicts a front sectional view of an impact protection structure for a vehicle including a localized energy dissipation structure shown along line A-A of FIG. 1 according to one or more embodiments shown or described herein;

FIG. 5 schematically depicts a front sectional view of the impact protection structure including a localized energy dissipation structure of FIG. 4 along line A-A of FIG. 1 shown after impact with a blunt-object barrier;

FIG. 6 schematically depicts a front sectional view of an impact protection structure for a vehicle including a localized energy dissipation structure shown along line A-A of FIG. 1 according to one or more embodiments shown or described herein;

FIG. 7 schematically depicts a perspective view of a battery support tray and impact protection structures for a vehicle according to one or more embodiments shown or described herein;

FIG. 8 schematically depicts a partial side view of a vehicle having an impact protection structure positioned along the side of the vehicle according to one or more embodiments shown or described herein;

FIG. 9 schematically depicts a front sectional view of an impact protection structure for a vehicle including a localized energy dissipation structure along line B-B of FIG. 7 according to one or more embodiments shown or described herein;

FIG. 10 schematically depicts a perspective view of a battery support tray for a vehicle according to one or more embodiments shown or described herein;

FIG. 11 schematically depicts a perspective view of a localized energy dissipation structure for a vehicle according to one or more embodiments shown or described herein;

FIG. 12 schematically depicts a perspective view of a battery support tray and impact protection structures for a vehicle according to one or more embodiments shown or described herein;

FIG. 13 schematically depicts a front view of an impact protection structure for a vehicle according to one or more embodiments shown or described herein;

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FIG. 14 schematically depicts a top view of an impact protection structure for a vehicle according to one or more embodiments shown or described herein;

FIG. 15 schematically depicts a top view of the impact protection structure for a vehicle of FIG. 14 undergoing an impact event with a blunt-object barrier;

FIG. 16 schematically depicts a top view of the impact protection structure for a vehicle of FIG. 14 undergoing an impact event with a blunt-object barrier;

FIG. 17 schematically depicts a top view of the impact protection structure for a vehicle of FIG. 14 undergoing an impact event with a blunt-object barrier; and

FIG. 18 hypothetically depicts a force-stroke plot diagrammatically depicting deformation of an impact protection structure undergoing an impact with a blunt-object barrier according to one or more embodiments shown and described herein.

DETAILED DESCRIPTION

FIGS. 1 and 2 generally depict vehicles incorporating impact protection structures that deform when impacted by a blunt-object barrier and limit damage to the vehicle from the blunt-object barrier. The impact protection structures deform when impacted by the blunt-object barrier, such that the impact protection structures absorb energy associated with the impact and prevent that energy from being transferred to the vehicle and/or the support structure of the vehicle. The impact protection structures include localized energy dissipation structures that extend a distance less than a distance the impact protection structures extend along the side sills of the vehicle. The localized energy dissipation structures allow placement of further impact protection structures in regions of low clearance and/or in discrete locations where additional impact protection is desired. The impact protection structures and vehicles incorporating the same will be described in more detail herein with specific reference to the appended drawings.

Referring now to FIG. 1, a partial side view of a vehicle 60 is depicted. The vehicle 60 includes a side sill 62 that extends along one side of the vehicle 60 from the front wheel 68a to the rear wheel 68b a side sill length 63. The vehicle 60 includes a corresponding side sill 62 along the opposite side of the vehicle 60 (not shown). An impact protection structure 100 is positioned along a side of the vehicle 60. The impact protection structure 100 is coupled to a support structure of the vehicle. As used herein, the phrase “support structure” may refer to a battery support tray (as described below), a vehicle frame or unibody 64 of the vehicle 60.

Referring now to FIGS. 1 and 2, a battery support tray 90 of a vehicle 60 is depicted. The battery support tray 90 includes a plurality of cross-support members 96 that are coupled to a tray floor 94. The cross-support members 96 may be coupled to end plates 92 positioned at the ends of the cross-support members 96 for attachment to the impact protection structures 100. The cross-support members 96 may be constructed to satisfy the requirements of stiffness and strength to provide support to the impact protection structure 100 during an impact event, as described below. In one embodiment, the cross-support members 96 include a plurality of components that are attached to each other. The cross-support members 96 may include hollow lumens arranged through their thickness. The cross-support members 96 may be made from a variety of materials including, without limitation, extruded aluminum alloy channels and steel channels.

In some embodiments, the impact protection structures 100 may be attached to both the vehicle frame or unibody 64

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and the battery support tray 90. In other embodiments, the impact protection structures 100 may be secured directly to the battery support tray 90 without the impact protection structures 100 being attached to the vehicle frame or unibody 64.

While specific mention is made to the use of impact protection structures 100 with battery support trays 90 for electric or hybrid-electric vehicles, it should be understood that impact protection structures 100 according to the present disclosure may be used in conjunction with conventional, gasoline or diesel-fueled vehicles.

The impact protection structure 100 includes an energy absorbing rail 108. In some embodiments, the energy absorbing rail 108 includes an interior rail 110 coupled to the battery support tray 90 and an exterior rail 120 coupled to the interior rail 110. In other embodiments, the energy absorbing rail 108 is a single, integral rail. As depicted in FIG. 2, both the interior rail 110 and the exterior rail 120 include multi-lumen structures. The lumens 124 of the exterior rail 120 are separated by exterior rail septa 125, as will be described in greater detail below. The interior and exterior rail 110, 120 may be extruded such that the wall thicknesses of the interior and exterior rails 110, 120 are generally uniform along a length 111 of the energy absorbing rail 108.

As depicted in FIG. 1, the impact protection structure 100 is coupled to the underside of the vehicle 60. A portion of the exterior rail 120 and the localized energy dissipation structure 130 of the impact protection structure 100 may be visible along the side of the vehicle 60. For example, in the embodiment depicted in FIG. 1, a portion of the exterior rail 120 is visible below the side sill 62 of the vehicle 60. However, in alternate embodiments, the impact protection structure 100 may be completely visible or completely shielded from view by trim or body components of the vehicle 60.

It should be understood that the battery support tray 90 may be modular and interchangeable for use in a variety of vehicle platforms. The interchangeability of the battery support tray 90 across a variety of vehicle platforms may allow the battery support tray 90 to be used across multiple vehicle lines, which may decrease costs associated with development and/or production of the vehicle 60. The impact protection structure 100, including the interior rail 110 and the exterior rail 120, may be designed to suit particular vehicle layout requirements, for example, by accommodating the packaging constraints of the particular vehicle and providing the desired side impact protection, while continuing to use the interchangeable battery support tray 90.

In certain end-user applications, components of the vehicle 60 may prevent installation of the impact protection structures 100 along an entire characteristic distance of the vehicle 60, for example along the entire side sill 62 of the vehicle 60. For example, suspension components (not shown) of the vehicle 60 that secure the wheels 68a, 68b to the vehicle frame or unibody 64 may require clearance in locations proximate to the impact protection structures 100 for installation and/or range of motion purposes. Accordingly, portions of the interior and/or exterior rails 110, 120 of the impact protection structures 100 may be removed from the interior and/or exterior rails 110, 120 to form relief zones 128 in the impact protection structures 100. As depicted in FIGS. 1 and 2, the relief zones 128 are formed by removing a portion of the exterior rail 120 to expose a septum 125 of the exterior rail 120. The relief zones 128 extend into the exterior rail 120 of the energy absorbing rail 108 and are positioned proximate to the wheels 68a, 68b of the vehicle 60.

The energy absorbing capacity of the energy absorbing rail 108 at positions of the relief zones 128 (depicted in FIGS. 1

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and 2 as being positioned at the furthest distance from the center of gravity 66 of the vehicle 60 in a forward direction 50 towards the front wheel 68a are reduced compared with the energy absorbing capacity of the energy absorbing rail 108 at positions away from the relief zones 128. However, the relief zones 128 are positioned at an offset distance 140 in an offset direction (i.e., in the forward direction 50) from the center of gravity 66 of the vehicle 60. In an impact event where a blunt-object barrier contacts the vehicle 60 at a position away from the center of gravity 66, the vehicle 60 will tend to rotate the vehicle around the blunt-object barrier. The rotation of the vehicle 60 around the blunt-object barrier reduces the energy that is transferred to the impact protection structure 100 because the impact causes the force to be applied in an oblique direction instead of normal to impact protection structure 100. As such, energy dissipation requirements of the impact protection structure 100 are generally lower at locations away from the center of gravity 66 of the vehicle 60. Further, at locations of the impact proximate to the relief zones 128, other vehicle structures such as body panels, door panels, and portions of the vehicle frame or unibody 64 may dissipate energy associated with an impact with a blunt-object barrier. Thus, the required energy dissipation of the energy absorbing rail 108 at positions proximate to the relief zones 128 may be reduced.

As used herein, “blunt-object barrier” 70 (as depicted in FIG. 5) refers to a pole-like barrier used in testing according to FMVSS 201 and 214. Such a pole-like barrier simulates vehicle impact with telephone poles, trees, concrete posts, and the like. However, impact protection structures 100 according to the present disclosure may be utilized to resist impact by a variety of blunt-objects including real-world impacts.

Still referring to FIGS. 1 and 2, a localized energy dissipation structure 130a is positioned within the relief zones 128 of the energy absorbing rail 108. As illustrated, the localized energy dissipation structure 130 is positioned adjacent to an opening created in a lumen 124 by the relief zone 128. By positioning the localized energy dissipation structure 130 within the relief zone 128, additional side impact protection can be provided to the vehicle 60 at locations proximate to the relief zones 128 without increasing the overall size of the impact protection structure 100. Such a localized energy dissipation structure 130 may allow for installation of various vehicle components and provide access for later maintenance of vehicle components, for example, maintenance of the battery packs 80 secured within the battery support tray 90 of the vehicle 60.

Referring now to FIG. 3, one embodiment of the localized energy dissipation structure 130 is depicted. The localized energy dissipation structure 130 includes an exterior profile 132 that generally corresponds to the interior profile of one of the lumens 124 of the energy absorbing rail 108. The exterior profile 132 of the localized energy dissipation structure 130 allows for a close fit between the localized energy dissipation structure 130 and the energy absorbing rail 108. The localized energy dissipation structure 130 may be a multi-lumen structure, for example, having a first and a second localized lumen 134a, 134b that extend along a localized energy dissipation structure length 138, which are separated by a septum 135. By incorporating a first and second localized lumen 134a, 134b, the localized energy dissipation structure 130 may have an increased resistance to buckling when a load is applied to the localized energy dissipation structure 130 than a localized energy dissipation structure that does not incorporate a first and second localized lumen 134a, 134b.

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The impact protection structure 100, including the energy absorbing rail 108 and the localized energy dissipation structure 130 may be made from a variety of materials including, for example, alloys of aluminum or steel. Some components of the impact protection structure 100 may be formed in an extrusion process such that the components have generally uniform wall thicknesses along their lengths. Alternatively, some components of the impact protection structure 100 may be fabricated as separate components that are secured to one another with mechanical fasteners (not shown). The mechanical fasteners may be, but are not limited to, pop rivets, solid core rivets, or self piercing rivets made from a variety of materials including, but not limited to, alloys of aluminum or steel. The mechanical fasteners may also be bolts and nuts or screws. The components of the impact protection structure 100 may also be secured to one another by a structural adhesive, for example an epoxy or an acrylic resin. Alternatively, or in addition, components of the impact protection structure 100 may be fabricated through a joining process, for example welding, including resistance spot welding, friction stir welding, gas tungsten arc welding, gas metal arc welding, or brazing, such that the components of the impact protection structure 100 are weldments.

Referring again to FIG. 1, another embodiment of the localized energy dissipation structure 130b is depicted, where the localized energy dissipation structure 130 is located internally to the energy absorbing rail 108. The localized energy dissipation structure 130b includes a localized energy dissipation structure length 138 that is less than the length 111 of the interior and/or exterior rails 110, 120 of the energy absorbing rail 108. The localized energy dissipation structure 130 is positioned along the energy absorbing rail 108 at a location where additional impact protection is desired. The localized energy dissipation structure 130b is coupled to the energy absorbing rail 108 at a plurality of securement positions 139 along the localized energy dissipation structure length 138. The plurality of securement positions 139 may be spaced apart from one another at interstitial positions between the securement positions 139.

Referring to FIG. 4, an embodiment of the localized energy dissipation structure 130 positioned internally to an enclosed lumen 124a of the energy absorbing rail 108 is depicted. In this embodiment, the energy absorbing rail 108 includes an interior rail 110 coupled to both the end plates 92 and the tray floor 94 of the battery support tray 90. The interior rail 110 is a multi-lumen structure having a first and second interior lumen 112a, 112b. The energy absorbing rail 108 also includes an exterior rail 120 coupled to the interior rail 110. In the depicted embodiment, the exterior rail 120 includes a first, second, third, and fourth exterior lumen 124a, 124b, 124c, 124d, each separated from one another by an exterior rail septum 125. The localized energy dissipation structure 130 is positioned within the first exterior lumen 124a at a pre-determined position along the length of the exterior rail 120.

The localized energy dissipation structure 130 is coupled to the exterior rail 120 of the energy absorbing rail 108 at a plurality of securement positions 139. In some embodiments, the localized energy dissipation structure 130 and the energy absorbing rail 108 are secured to one another with mechanical fasteners. The mechanical fasteners may be, but are not limited to, pop rivets, solid core rivets, or self piercing rivets made from a variety of materials including, but not limited to, alloys of aluminum or steel. The mechanical fasteners may also be bolts and nuts or screws. The localized energy dissipation structure 130 may also be secured to the energy absorbing rail 108 by a structural adhesive, for example an epoxy or an acrylic resin. Alternatively, or in addition, the

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localized energy dissipation structure **130** may be secured to the energy absorbing rail **108** through a joining process, for example welding, including resistance spot welding, friction stir welding, gas tungsten arc welding, gas metal arc welding, or brazing.

The interior rail **110** and the exterior rail **120** including the localized energy dissipation structure **130** each have an associated interior buckling load limit or exterior buckling load limit. The interior or exterior buckling load limit, as used herein, refers to the maximum load that can be applied to the interior rail **110** or the exterior rail **120** before one of the lumens loses stability and collapses in an inboard direction. The buckling load limit of any of the interior lumens **112a**, **112b** or the exterior lumens **124a**, **124b**, **124c**, **124d** may be simulated computationally, for example, using a non-linear finite element analysis program. The buckling load limit of the lumens may be approximated by calculating the bending strength of each of the lumens when a force is applied to the exterior rail **120** in an inboard direction. The buckling load limit of any of the lumens, and therefore the interior rail **110** and exterior rail **120**, may be affected by the shape and thickness of the walls surrounding the lumens.

Referring now to FIG. 5, the energy absorbing rail **108** of FIG. 4 is depicted undergoing an impact event with a blunt-object barrier **70**. As depicted in FIG. 5, as the exterior rail **120** contacts the blunt-object barrier **70**, the first exterior lumen **124a** buckles as the buckling load limit of the first exterior lumen **124a** is exceeded. In addition, because the localized energy dissipation structure **130** is positioned within the first exterior lumen **124a** of the exterior rail **120**, as the first exterior lumen **124a** deforms, the localized energy dissipation structure **130** deforms. The buckling of the localized energy dissipation structure **130** increases the energy dissipated at the contact zone along the energy absorbing rail **108**, thereby reducing the energy caused by the impact event between the energy absorbing rail **108** and the blunt-object barrier **70**. The increase in energy dissipation by the localized energy dissipation structure **130** may decrease the energy due to the impact event that is transferred towards the battery support tray **90**, thereby reducing the likelihood of damage to the battery packs (not shown).

In the embodiment depicted in FIGS. 4 and 5, the buckling load limit of the exterior rail **120** is less than the buckling load limit of the interior rail **110**. As such, the exterior rail **120**, including the localized energy dissipation structure **130**, buckles before the interior rail **110**. By preferentially buckling the exterior rail **120** before the interior rail **110**, the deformation of the energy absorbing rail **108** may be controlled such that the deformed shape of the energy absorbing rail **108** does not induce an unsustainable moment load into the end plates **92** or tray floor **94** of the battery support tray **90**.

In the embodiment depicted in FIGS. 4 and 5, the localized energy dissipation structure **130** increases the energy dissipation of the impact protection structure **100** at a discrete location along the length **111** of the interior and exterior rails **110**, **120**. The localized energy dissipation structure **130** may provide a comparable energy dissipation to an exterior rail **120** having an increased wall thickness along the entire length **111** of the exterior rail **120**, but without incurring the increase in weight associated with an increase in wall thickness along the entire length **111**. Thus, the localized energy dissipation structure **130** may dissipate energy more efficiently in regard to weight than an increase in wall thickness along the entire length **111** of the exterior rail **120**.

Referring now to FIG. 6, another embodiment of the impact protection structure **100** is depicted. In this embodiment, portions of the exterior rail **120** have been removed, as

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described above, exposing the exterior rail septum **125** separating the second exterior lumen **124b** from the third exterior lumen **124c**, thereby forming a relief zone **128** in the exterior rail **120**. The localized energy dissipation structure **130** is a multi-lumen structure having a first and second localized lumens **134a**, **134b** that are separated from one another by a septum **135**. The localized energy dissipation structure **130** is positioned proximate to the relief zone **128** within the third exterior lumen **124c**, which remains enclosed. The localized energy dissipation structure **130** extends along the exterior rail **120** a partial distance less than the length **111** of the exterior rail **120**. The localized energy dissipation structure **130** depicted in FIG. 6 provides additional strength to the exterior rail **120** that increases the energy dissipation capability of the exterior rail **120**. Further, by positioning the localized energy dissipation structure **130** within the third exterior lumen **124c**, the impact protection structure **100** exhibits an enhanced energy dissipation capability without increasing the size of the exterior rail **120**.

Referring now to FIGS. 7-9, another embodiment of the impact protection structure **100** including a plurality of localized energy dissipation structures **230** is depicted. In this embodiment, the localized energy dissipation structures **230** are coupled to the battery support tray **90** of the vehicle. Each of the localized energy dissipation structures **230** has a localized energy dissipation structure length **238** that is less than the side sill length **63** extending from the front wheel well **69a** to the rear wheel well **69b** of the vehicle **60**, as depicted in FIG. 1. The localized energy dissipation structures **230** are positioned along the battery support tray **90** such that the plurality of localized energy dissipation structures **230** provides impact protection to the battery support tray **90**, and therefore the vehicle **60**, along the entire side sill length **63**.

In the embodiment depicted in FIGS. 7-9, adjacent localized energy dissipation structures **230** are overlapped with one another along the length **138** of the localized energy dissipation structures **230**. Accordingly, the exterior contour **232** of the localized energy dissipation structures **230** may be shaped such that the top and the bottom of the localized energy dissipation structures "nest" with one another, as depicted in FIG. 9. As depicted in FIG. 8, the localized energy dissipation structures **230** may be biased relative to the battery support tray **90** such that a rearward portion **236** of a first localized energy dissipation structure **230** is positioned a vertical distance below a forward portion **237** of a second localized energy dissipation structure **230**, where the first localized energy dissipation structure **230** is positioned in a forward direction **50** of the second localized energy dissipation structure **230**. Such positioning of the localized energy dissipation structures **230** may create an "offset nesting" arrangement that increases the protection to an impact event with a blunt-object barrier **70** by increasing the available localized energy dissipation structures **230** to absorb the impact. The offset nesting arrangement may also be helpful in shedding debris such as water, snow, and road grime from the impact protection structure **100**. The localized energy dissipation structures **230** may include weep holes to shed debris that collects inside the localized energy dissipation structures **230**. In some embodiments, the overlap distance **242** of adjacent localized energy dissipation structures **230** may be from about 20% to about 70% of the length **238** of the localized energy dissipation structure. In a particular embodiment, the overlap distance **242** of adjacent energy dissipation structures **230** may be about 50% of the length **238** of the localized energy dissipation structure.

While the localized energy dissipation structures **230** depicted in FIG. 8 are depicted to contact one another, it

should be understood that the localized energy dissipation structures **230** may be spaced apart from one another to provide clearance to shed debris such as water, snow, road grime, and the like.

Referring now to FIG. **9**, the localized energy dissipation structures **230** may be a multi-lumen structure that includes a first and a second lumen **234a**, **234b**. The first and second lumens **234a**, **234b** may be positioned within the localized energy dissipation structures **230** to provide a pre-determined buckling load limit, based on the end-user application.

When a vehicle **60** having the localized energy dissipation structure **230** is subject to an impact load from a blunt-object barrier, the localized energy dissipation structures **230** proximate to the blunt-object barrier contact the blunt-object barrier and being to deform. As the localized energy dissipation structures **230** elastically and/or plastically deform, the load applied to the localized energy dissipation structures **230** exceeds the buckling load limit of the localized energy dissipation structures **230**, causing the localized energy dissipation structures **230** to buckle due to the compressive stresses applied by the blunt-object barrier. Because the localized energy dissipation structures **230** are coupled to the battery support tray **90** independently of one another, one of the localized energy dissipation structures **230** may buckle, while an adjacent localized energy dissipation structure **230** does not.

Referring now to FIGS. **10** and **11**, components of another embodiment of the battery support tray **90** and localized energy dissipation structures **430** are depicted. Referring now to FIG. **10**, the end plates **92** of the battery support tray **90** include locating slots **394**. The locating slots **394** extend a partial distance along the side of the battery support tray **90**. Referring now to FIG. **11**, each of the plurality of localized energy dissipation structures **430** include a support tab **440** that extends away from the plurality of localized lumens **434a**, **434b**, **434c**. The exterior contour **432** of the localized energy dissipation structures **430** is shaped to allow the localized energy dissipation structures **430** to “nest” with one another. When the localized energy dissipation structures **430** are installed in position on the battery support tray **90**, the support tabs **440** of the localized energy dissipation structures **430** are inserted into the locating slots **394** of the end plates **92**. By positioning the support tabs **440** in the locating slots **394**, the position and orientation of the plurality of localized energy dissipation structures **430** can be maintained relative to the battery support tray **90** and to each other.

Still referring to FIG. **11**, the localized energy dissipation structures **430** may include interlocking tabs **442** extending from one of the top or the bottom surface of the localized energy dissipation structure **430** (depicted in FIG. **11** as extending from the top surface of the localized energy dissipation structure **430**), and interlocking slots **444** that extend along one of the bottom surface or the top surface of the localized energy dissipation structure **430** (depicted in FIG. **11** as extending from the bottom surface of the localized energy dissipation structure **430**). When the localized energy dissipation structures **430** are assembled in position on the battery support tray **90**, the interlocking tabs **442** are positioned within the interlocking slots **444** such that adjacent localized energy dissipation structures **430** are interlocked with one another. Interlocking of adjacent localized energy dissipation structures **430** may assist with dissipating energy associated with impact with a blunt-object barrier. For example, when one of the localized energy dissipation structures **430** is impacted by a blunt-object barrier, the interlocking tabs **442** and the interlocking slots **444** may transfer energy from the localized energy dissipation structure **430**

absorbing the majority of the energy from the impact to adjacent localized energy dissipation structures **430**.

Referring now to FIGS. **12-17**, another embodiment of the impact protection structure **300** for a vehicle is depicted. In this embodiment, the impact protection structure **300** includes a plurality of elongated frustums **310** coupled to the battery support tray **90** of the vehicle. As depicted in FIG. **12**, the impact protection structures **300** are coupled to the battery support tray **90** such that the elongated frustums **310** extend in the forward direction **50** of the vehicle. However, it should be understood that the impact protection structures **300** may be positioned such that the elongated frustums **310** extend in a rearward direction **52** as well as in one of the lateral directions **56** of the vehicle.

Referring now to FIGS. **13** and **14**, the elongated frustums **310** of the impact protection structure **300** have a truncated-pyramid shape that includes a plurality of lateral faces **312** that extend outwards to a distal contact face **318**. While the elongated frustums **310** depicted include four lateral faces **312**, it should be understood that the elongated frustums **310** may include any of a number of lateral faces **312** geometrically arranged, including an elongated frustum **310** having a cone-like shape and, therefore, a single lateral face **312**. The lateral faces **312** extend away from the distal contact face **318** to mounting flanges **314**. The mounting flanges **314** of the elongated frustum **310** are coupled to a mounting bracket **322**. The mounting flanges **314** may include a plurality of positioning datums **316** that assist with alignment of the elongated frustum **310** to the mounting bracket **322**.

The impact protection structure **300** may also include a plurality of tie straps **320** that are coupled to adjacent elongated frustums **310**. The tie straps **320** distribute load associated with an impact event with a blunt-object barrier **70** (not shown) away from the point of impact with the distal contact face **318** to adjacent elongated frustums **310**, thereby distributing the load and stabilizing the elongated frustums **310** and enhancing performance of the impact protection structure **300**. The tie straps **320** may extend along a majority of the lateral faces **312** of the elongated frustums **310**. The tie straps **320** may be coupled to the elongated frustums **310** at a plurality of attachment points **323**. The tie traps **320** may be coupled to the elongated frustums **310** at the attachment points **323** by mechanical fasteners, structural adhesive, structural spot welds, or a combination thereof.

In the embodiment depicted in FIGS. **12-14**, the lateral face **312** of the elongated frustum **310** that is at the lowest vertical position is angled upwards from the mounting bracket **322** to the distal contact face **318**. The angled orientation of the lowest vertically positioned lateral face **312** may assist with shedding debris such as water, snow, road grime, and the like, from the impact protection structure **300**.

The elongated frustum **310** may be fabricated using a variety of techniques including deep-draw stamping, hydroforming, and/or sheet metal bending and welding, such that the elongated frustums **310** include weldments. In some embodiments, the interior volume of the elongated frustums **310** defined by the lateral faces **312**, the distal contact face **318**, and the mounting flanges **314** may be hollow. In other embodiments, the interior volume of the elongated frustums **310** may be filled with an energy absorbing material.

Referring now to FIGS. **15-17**, an impact event between an impact protection structure **300** having a plurality of elongated frustums **310** and a blunt-object barrier **70** is depicted. When a vehicle having the impact protection structure **300** that includes a plurality of elongated frustums **310** is subject to an impact load from a blunt-object barrier **70**, the elongated frustums **310** proximate to the blunt-object barrier **70** contact

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the blunt-object barrier 70 and being to deform. As the elongated frustums 310 elastically and/or plastically deform, the load applied to the elongated frustums 310 exceeds the buckling load limit of the elongated frustums 310, causing the elongated frustums 310 to buckle inwards towards the battery support tray 90 due to the compressive stresses applied by the blunt-object barrier 70. Depending on the location of the blunt-object barrier 70 relative to the elongated frustums 310, a load that is non-orthogonal to the distal contact face 318 may tend to bend the elongated frustum 310, causing it to collapse in a direction corresponding to the direction of the load. As the elongated frustum 310 continues to buckle, the tie straps 320 may distribute the load from the elongated frustum 310 contacting the blunt-object barrier 70 to elongated frustums 310 that are spaced apart from the blunt-object barrier 70. The tie straps 320 stabilize each of the elongated frustums 310 by distributing a portion of the load associated with the impact with the blunt-object barrier 70 to other elongated frustums 310 in the impact protection structure 300.

Referring now to FIG. 15, the impact protection structure 300 includes three elongated frustums 310 that are coupled to one another by tie straps 320 at two positions along the top and bottom lateral faces 312. The tie straps 320 segregate the elongated frustums 310 into a plurality of discrete deformation zones. A first deformation zone 330 is positioned between the contact faces 318 of the elongated frustums 310 and the outer-most tie strap 320. A second deformation zone 332 is positioned between the outer-most tie strap 320 and the inner-most tie strap 320. The third deformation zone 334 is positioned between the inner-most tie strap 320 and the mounting bracket 322 of the impact protection structure 300. Referring to FIG. 15, when the elongated frustum 310 positioned in the center of the impact protection structure 300 is contacted by a blunt object barrier 70, the elongated frustum 310 contacting the blunt-object barrier 70 begins to deform in the first deformation zone 330.

Referring now to FIG. 16, as the blunt-object barrier 70 continues to travel towards the mounting bracket 322, the elongated frustum 310 contacting the blunt-object barrier 70 continues to collapse and deform. As the elongated frustum 310 contacting the blunt-object barrier 70 collapses in the first and second deformation zones 330, 332, the outer-most tie strap 320 applies a force to the non-contacting elongated frustums 310, causing the non-contacting elongated frustums 310 to deform. The tie strap 320 transfers energy caused by the impact between the blunt-object barrier 70 and the contacting elongated frustum 310 to the non-contacting elongated frustums 310, such that the non-contacting elongated frustums 310 dissipate energy associated with the impact. The deformation of the non-contacting elongated frustums 310 may be positioned in the same deformation zone as that of the contacting elongated frustum 310. Thus, deformation of the contacting elongated frustum 310 in the first and second deformation zones 330, 332 may cause deformation of the non-contacting elongated frustums 310 in the first and second deformation zone 332. Further, the tie strap 320 may provide structural reinforcement to local regions of the elongated frustums 310. The deformation of the elongated frustums 310 is limited to occur in the first and second deformation zones 330, 332, while local regions of the elongated frustums 310 supported by the tie straps 320 remain undeformed.

Referring now to FIG. 17, the contacting and non-contacting elongated frustums 310 continue to deform as the elongated frustums 310 dissipate energy associated with the impact with the blunt-object barrier 70. As depicted in FIG. 17, the contacting frustum 310 deforms in the first, second, and third deformation zones 330, 332, 334 as the blunt-object

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barrier 70 approaches the mounting bracket 322. The outer-most and inner-most tie straps 320 apply loads to the non-contacting elongated frustums 310 as to dissipate energy associated with the impact. Further, as is depicted in FIG. 17, the deformation of the non-contacting elongated frustums 310 may be positioned in the same deformation zone as that of the contacting elongated frustum 310. Thus, deformation of the contacting elongated frustum 310 in the first, second, and third deformation zones 330, 332, 334 may cause deformation of the non-contacting elongated frustums 310 in the first, second, and third deformation zones 330, 332, 334.

Referring now to FIG. 18, a hypothetical force-stroke plot diagrammatically depicts deformation of the impact protection structure 300 undergoing an impact with a blunt-object barrier. The individual curves of the force-stroke plot represent the energy dissipation of the first, second, and third deformation zones 330, 332, 334 as the impact protection structure 300 undergoes the impact event. Because of the taper of the elongated frustums 310 from the distal contact face 318 to the mounting bracket 322, the first, second, and third deformation zones 330, 332, 334 have progressively increasing energy dissipation capability, which is reflected in the ability of the elongated frustums 310 to resist progressively greater deformation force as the first, second, and third deformation zones 330, 332, 334 buckle. Without being bound by theory, the even taper of the elongated frustums 310 provide force-stroke curves having approximately the same shape for the first, second, and third deformation zones 330, 332, 334, or are "symmetrical." The symmetric force-stroke curves reflect that maximum force F_{MAX} dissipated by the impact protection structure 300 is progressive and does not contain sharp changes in slope, representative of sudden impact loads being transferred to the vehicle. The hypothetical force-stroke plot depicting the response of the impact protection structure 300 with a blunt-object barrier (i.e., increase in force with each successive buckle and symmetry of deformation zones 330, 332, 334) reflects computational results shown by nonlinear finite element analysis of the described shape.

It should now be understood that impact protection structures may include localized energy dissipation structures that may be used in conjunction with other energy absorbing structures as to provide a local increase in energy dissipation capability of the energy absorbing structures. Impact protection structures that incorporate localized energy dissipation structures use material more efficiently, such that a weight penalty associated with increase energy dissipation is managed. Impact protection structures including localized energy dissipation structures according to the present disclosure may be positioned at a variety of orientations on the vehicle to provide increased protection from impact with blunt-object barriers in a variety of vehicle orientations.

It is noted that the terms "substantially" and "about" may be utilized herein to represent the inherent degree of uncertainty that may be attributed to any quantitative comparison, value, measurement, or other representation. These terms are also utilized herein to represent the degree by which a quantitative representation may vary from a stated reference without resulting in a change in the basic function of the subject matter at issue.

While particular embodiments have been illustrated and described herein, it should be understood that various other changes and modifications may be made without departing from the spirit and scope of the claimed subject matter. Moreover, although various aspects of the claimed subject matter have been described herein, such aspects need not be utilized in combination. It is therefore intended that the appended

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claims cover all such changes and modifications that are within the scope of the claimed subject matter.

The invention claimed is:

1. An impact protection structure for a vehicle comprising:
a side sill of the vehicle extending a side sill distance
between a front wheel well and a rear wheel well; and
a plurality of localized energy dissipation structures
coupled to the side sill, the localized energy dissipation
structures each having a localized energy dissipation
structure length between the front wheel well and the
rear wheel well that is less than the side sill distance,
each localized energy dissipation structure of the plural-
ity of energy dissipation structures has a forward portion
nearer the front wheel well and a rearward portion nearer
the rear wheel well;

wherein a first localized energy dissipation structure and a
second, adjacent localized energy dissipation structure
are each positioned in a slanting orientation with respect
to the side sill such that the forward portion of the second
localized energy dissipation structure overlaps the rear-
ward portion of the first adjacent energy dissipation
structure and the forward portion of the first energy
dissipation structure is nearer the front wheel well than
the forward portion of the second localized energy dis-
sipation structure.

2. The impact protection structure of claim 1, wherein the
second localized energy dissipation structure overlaps the
first localized energy dissipation structure from about 20% of
a energy dissipation structure length to about 70% of the
energy dissipation structure length.

3. The impact protection structure of claim 1, wherein the
plurality of localized energy dissipation structures comprise a
plurality of energy dissipation lumens extending along each
of their energy dissipation structure lengths.

4. The impact protection structure of claim 1, wherein the
forward portion of the second localized energy dissipation
structure is nested with the rearward portion of the first local-
ized energy dissipation structure.

5. An impact protection structure for a vehicle comprising:
a side sill of the vehicle extending a side sill distance
between a front wheel well and a rear wheel well; and
a plurality of localized energy dissipation structures
coupled to the side sill, the localized energy dissipation
structures each having a localized energy dissipation
structure length less than the side sill distance, each
localized energy dissipation structure of the plurality of
energy dissipation structures has a forward portion
nearer the front wheel well and a rearward portion nearer
the rear wheel well;

wherein the rearward portion of a first localized energy
dissipation structure is nested and in contact with the
forward portion of a second, adjacent energy dissipation
structure.

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6. The impact protection structure of claim 5, wherein the
forward portion of the first localized energy dissipation struc-
ture is nearer the front wheel well than the forward portion of
the second localized energy dissipation structure.

7. The impact protection structure of claim 5, wherein the
plurality of localized energy dissipation structures at least
partially overlap one another along the localized energy dis-
sipation structure length.

8. The impact protection structure of claim 7, wherein the
second localized energy dissipation structure overlaps the
first localized energy dissipation structure from about 20% of
a energy dissipation structure length to about 70% of the
energy dissipation structure length.

9. The impact protection structure of claim 5, wherein the
plurality of localized energy dissipation structures comprise a
plurality of energy dissipation lumens extending along each
of their energy dissipation structure lengths.

10. An impact protection structure for a vehicle compris-
ing:

- a side sill of the vehicle extending a side sill distance
between a front wheel well and a rear wheel well; and
a plurality of localized energy dissipation structures
coupled to the side sill, the localized energy dissipation
structures each having a localized energy dissipation
structure length between the front wheel well and the
rear wheel well that is less than the side sill distance,
each localized energy dissipation structure of the plural-
ity of energy dissipation structures has a forward portion
nearer the front wheel well and a rearward portion nearer
the rear wheel well;

wherein a first localized energy dissipation structure and a
second, adjacent localized energy dissipation structure
are each positioned in a slanting orientation with respect
to the side sill such that the forward portion of the second
localized energy dissipation structure overlaps and con-
tacts the rearward portion of the first adjacent energy
dissipation structure.

11. The impact protection structure of claim 10, wherein
the second localized energy dissipation structure overlaps the
first localized energy dissipation structure from about 20% of
a energy dissipation structure length to about 70% of the
energy dissipation structure length.

12. The impact protection structure of claim 10, wherein
the plurality of localized energy dissipation structures com-
prise a plurality of energy dissipation lumens extending along
each of their energy dissipation structure lengths.

13. The impact protection structure of claim 10, wherein
the forward portion of the second localized energy dissipation
structure is nested with the rearward portion of the first local-
ized energy dissipation structure.

* * * * *